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Year-End Report
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This report summarizes work performed under Subcontract No. B599727 between Nov. 12, 2012 and Sept. 30, 2013. Activities during this period included the deployment of a WindCube lidar at the Atmospheric Radiation Measurement (ARM) site in northern Oklahoma and the planning and execution of a scanning lidar field campaign at the ARM site. Work under the subcontract will be completed in association with the LDRD project entitled "Forecasting and UQ of power from intermittent renewable energy sources."

Fall/Winter 2012/13

In November 2012, a WindCube lidar owned by LLNL was deployed at the ARM site. The lidar was co-located with a 60-m meteorological tower so that measurements from the lidar could be directly compared to measurements from a sonic anemometer on the tower. The purpose of the field experiment was to determine the accuracy of lidar turbulence measurements in comparison to point measurements made by a standard tower-mounted sonic anemometer.

Lidar turbulence measurements are subject to three main systematic sources of error: averaging in the probe volume, averaging in the scan circle, and contamination of velocity variances by cross-components of the Reynolds stress tensor (Sathe et al. 2011). Averaging does not have a large effect on mean wind speeds but tends to act as a low-pass filter for turbulence, preventing the measurement of small-scale, high-frequency turbulence and causing underestimation of velocity variances. However, variance contamination tends to increase variance values, partially masking the effect of volume averaging. Our findings from the fall lidar experiment indicated that u and v variances were generally overestimated in comparison to sonic anemometer variances, particularly under unstable conditions (Fig. 1). This agrees with the findings of Sathe et al. (2011) from a similar study in Denmark.

Two of the systematic errors (averaging in the scan circle and contamination of velocity variances) can be mitigated by using research-grade scanning lidars with customizable scanning strategies. Thus, a second lidar experiment was planned for spring and summer 2013 after initial analysis of the fall 2012 results.

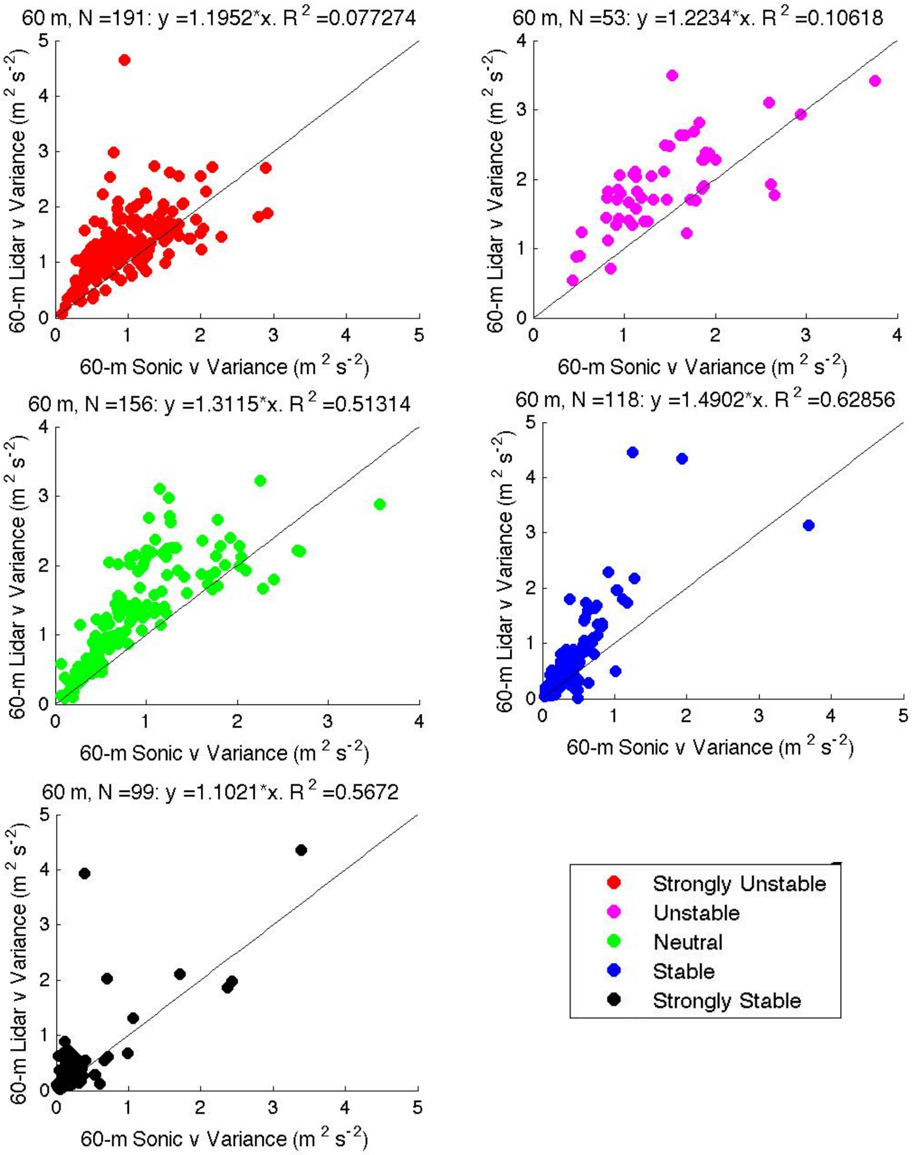

Fig. 1: Scatter plots of sonic and lidar v variance from November 2012 to January 2013. Different colors correspond to atmospheric stability classifications and 1:1 line is shown for reference.

Spring/Summer 2013

The first half of the spring semester was spent taking the University of Oklahoma's General Exam. I passed the General Exam in March 2013 and was promoted to Ph. D. candidate.

Planning for the summer lidar campaign at the ARM site began in May 2013. A Halo scanning lidar owned by the University of Oklahoma (OU) and a Galion scanning lidar rented by LLNL were deployed at the ARM site in early June.

Three primary scanning strategies were used during the campaign. During the first week of the experiment, the OU Halo lidar and the Galion lidar were pointed 105 m above the ARM Halo lidar (the first useable range gate of the ARM Halo lidar). As the ARM Halo lidar was pointed vertically and the OU Halo and Galion lidar was located in approximately orthogonal directions, a tri-Doppler technique was used to deduce the three-dimensional wind vector every 1 second. The wind speed and velocity variance derived from the tri-Doppler technique were compared to measurements made by the WindCube lidar at 105 m (Figs. 2–3). Corrections were made for differences in timestamps and orientations among the lidars and measurements were interpolated to the same 1-second grid. In addition, the Lenschow (2000) method was used to eliminate instrument noise from the velocity variance estimates.

While the mean wind speeds and directions between the two measurement techniques were nearly identical, more high-frequency fluctuations appeared to be present in the time series of the tri-Doppler measurements (Fig. 2). This is likely because the WindCube lidar averages velocity measurements over a scanning circle, which has a diameter of approximately 110 m at a height of 105 m above ground level. In contrast, the tri-Doppler measurements were taken at approximately one point in space and were limited only by the probe volume of the lidars, which was 30 m. However, the velocity variances derived from the tri-Doppler data were not always higher than the variances derived from the WindCube data (Fig. 3). This discrepancy is likely related to velocity variance contamination of the WindCube data, as previously discussed. Thus, one of the primary goals of the summer lidar experiment was to attempt to quantify and mitigate the velocity variance contamination.

In order to eliminate velocity variance contamination, Sathe and Mann (2012) developed a six-beam lidar scanning technique. By using six beams, the six unique elements of the Reynolds stress tensor can be determined independently. This technique had not yet been evaluated experimentally, so the summer lidar experiment at the ARM site provided an excellent opportunity to evaluate the technique. For the second week of the experiment, the Galion lidar mimicked the five-beam scanning technique of the WindCube lidar (four cardinal directions plus one vertical beam), while the OU Halo lidar used the six-beam technique of Sathe and Mann (2012). Preliminary processing and analysis has begun on the five- and six-beam data.

During the final week of the experiment, the OU and ARM Halo lidars and the Galion lidar were used to build a “virtual tower” over the WindCube lidar. The three scanning lidars pointed to several heights above the WindCube lidar (25, 60, 100, 200, 350, and 500 m). Each height was scanned for thirty minutes before the lidars changed their elevation angles and moved on to the next height. The 25- and 60-m heights corresponded to sonic anemometers on the meteorological tower at the ARM site. Analysis on these data will begin soon and will allow for a direct comparison between WindCube, tri-Doppler lidar, and sonic anemometer measurements of velocity variance.

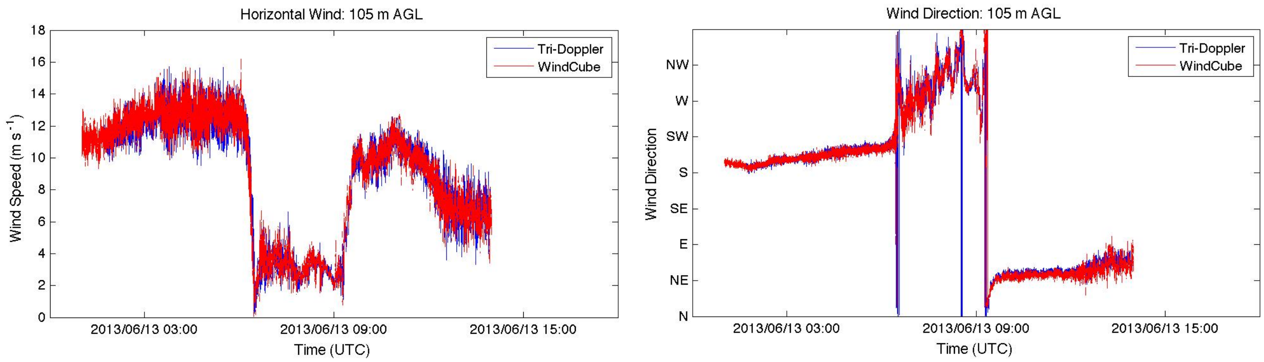

Fig. 2: Comparison of 1-s horizontal wind speed (left) and wind direction data (right) from June 13, 2013 from tri-Doppler analysis and WindCube lidar.

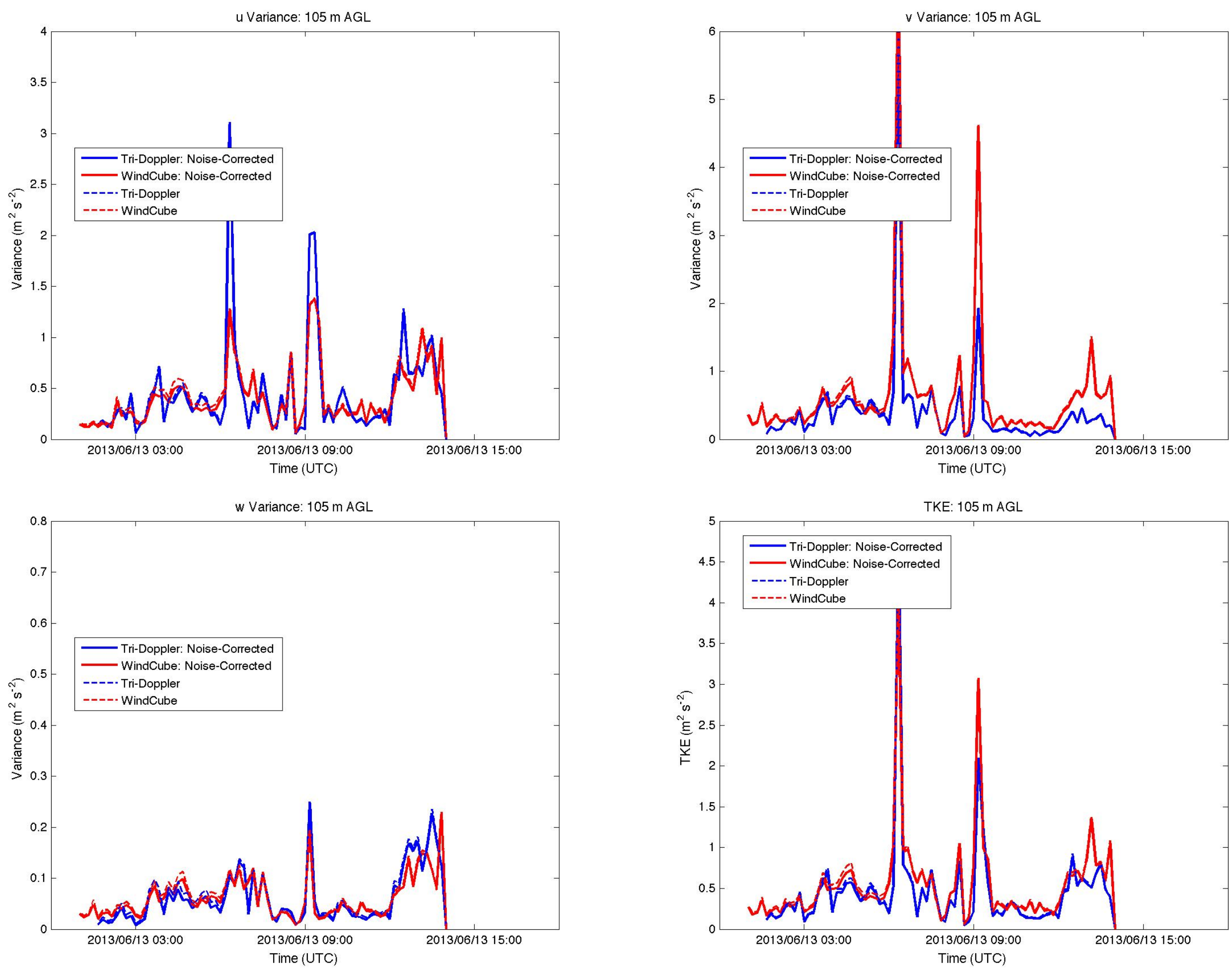

Fig. 3: Comparison of velocity variances and turbulence kinetic energy (TKE) from June 13, 2013 from tri-Doppler analysis and WindCube lidar.

References

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